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(54) MICROCAVITY SEMICONDUCTOR LASER

HALBLEITERLASER MIT MIKRORESONATOR

LASER A SEMI-CONDUCTEUR A MICROCAVITE

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D s ription

[0001] This invention was made with Government support under Grant Number: ECS-9210434 awarded by the National Science Foundation and Grant Number: F30602-94-1-0003 awarded by the Advanc d R s arch Project Agency of the Department of Defense. The Government may have certain rights in the invention.

[0002] The present invention relates to microcavity semiconductor lasers and, more particularly, to microdisk, microcylinder, microannulus and like semiconductor lasers.

[0003] Microcavity semiconductor lasers recently have been described for operation at liquid nitrogen temperature and room temperature. Such microcavity semiconductor lasers employ an active lasing medium that supports optical modes in the form of a whispering gallery mode where photons skimming around the circumference of a microdisk or microcylinder having an appropriately small diameter are continually totally reflected. The thin microdisk or microcylinder is positioned in a surrounding medium (e.g. air) having a high contrast of refractive index relative to that of the active lasing medium such that the optical mode is strongly confined inside the microdisk or microcylinder in the vertical direction and coupled to the active lasing medium comprising one or more quantum wells. For example, a whispering-gallery-mode microdisk semiconductor laser is described by McCall et al. in "Whispering-gallery mode microdisk lasers" in Appl. Phys. Lett. 60, (3), 20 January 1992. A whispering-gallery-mode microcylinder semiconductor laser is described by Levi et al. in "Room-temperature lasing action in $In_{0.51}Ga_{0.49}P/In_{0.2}Ga_{0.8}As$ microcylinder laser diodes" in Appl. Phys. Lett. 62, (17), 26 April 1993.

[0004] Microcavity semiconductor lasers are advantageous as compared to conventional semiconductor lasers in being much smaller in size and requiring substantially less minimum operating current (power) in the range of microwatts. However, there is no directional coupling of light out from such microcavity lasers. In fact, the photons are strongly confined inside the microdisk or microcylinder. This is disadvantageous in that a directional coupling of light out of the laser is necessary for useful applications.

[0005] Recently, in "Directional light coupling from microdisk lasers", Appl. Phys. Lett. 62, 561 (1993) an asymmetric point was introduced into a single circular microdisk to provide a location of increased quantity of lasing light to leak out from the point of asymmetry. Moreover, there has been a suggestion to provide grating fabricated directly on the microdisk to couple light therefrom. However, as a result of the small size of the microdisk, fabrication of grating or other light output coupling structur thereon is difficult to achieve without at the sam time adversely affecting the Q valu (quality factor) of the microcavity and th low lasing threshold.

[0006] In the paper "Double-disk structure for output coupling in microdisk lasers" by Chu et al, Appl. Phys. L tt. 65 (25), December 1994, p. 3167-3169, a double-disk structure is disclosed to couple light from a microdisk laser by the leakage of photons from a lower lasing disk to a top waveguiding disk. The waveguiding disk has an opening to dir ct light out from the double-disk structure.

[0007] According to the present invention, a laser comprises a first micromember having a lasing microcavity with a substantially circular cross-sectional periphery and a second waveguiding micromember spaced from the first micromember in a different plane and optically coupled to the first micromember, the second waveguiding micromember including a light output coupling comprising an arcuate output waveguide encircling a portion of the second waveguide member for providing light output from the laser.

[0008] The present invention is able to provide microcavity semiconductor lasers having features amenable for coupling light out from the laser without substantially adversely affecting the Q value and the low lasing threshold of the microcavity.

[0009] Further, the present invention is able to provide microcavity semiconductor lasers having features amenable for coupling light out from the laser to integrated optical circuits.

[0010] The micromembers may be a microdisk, microcylinder or microannulus, the first micromember having a lasing microcavity (one or more quantum wells) with a circular cross-sectional periphery.

[0011] The first and second micromembers are preferably at a different epitaxial level during fabrication of the laser by layer growth processes. The first lasing micromember and the second waveguiding micromember are optically coupled by, for example, resonant photon coupling by being spaced apart a selected distance from one another with a material having a lower refractive index disposed between the micromembers. The first lasing micromember and second waveguiding micromember are spaced apart by a distance selected to provide a given coupling efficiency therebetween. The high Q value and low lasing threshold of the lasing microcavity is maintained by providing a light output coupling on the second waveguiding micromember, rather than on the first lasing micromember.

[0012] In a particular embodiment of the invention, the first micromember comprises one or more InGaAs semiconductor microdisks, microcylinders, or microannulus as quantum wells separated by appropriate barrier layers and the second waveguiding micromember comprises a InGaAsP semiconductor microdisk, microcylinder, or microannulus. The optical coupling can comprise a low refractive index InP pedestal, microcylinder or microannulus.

[0013] The lasers of the present invention provide the advantages associated with microcavity semiconductor lasers while providing light output coupling from the laser that is usable in a servic application and that is com-

patible with integrat d optical circuits.

[0014] Th above objects and advantages of th present invention will become more readily apparent from the following detailed description taken with the following drawings.

Figure 1 is a schematic view of a microcavity (microdisk) laser similar to that described in the paper "Double-disk structure for output coupling in microdisk lasers" by Chu et al;

Figure 2 is a graph of coupling percentage versus coupling length for a double-disk laser with a spacing between microdisks of 0.65 microns;

Figure 3 is a graph of the lasing spectra versus wavelength for a double-microdisk laser;

Figure 4 is a photograph of edge-emitting lasing light output from the opening in the upper waveguiding microdisk of the laser of Fig. 1 at a wavelength of 1.5 microns;

Figure 5 is a schematic view of an alternative microcavity (microcylinder) laser;

Figure 6 is a schematic view similar to Figure 5 of a microcavity (microcylinder) laser including a light output coupling waveguide integral with the lower waveguiding microcylinder;

Figure 7 is a schematic view of a double microcylinder laser showing its layered structure;

Figure 8 is a schematic view of a microcavity laser according to one embodiment of the invention including an arcuate waveguide spaced about and encircling a portion of the circumferential periphery of the lower micromember; and,

Figure 9 is a schematic view of a microcavity laser including an arcuate waveguide spaced about and encircling a portion of the circumferential periphery of a lower microannulus pursuant to another embodiment of the invention.

[0015] Referring to Figure 1, a microcavity semiconductor laser is illustrated schematically as including a first lower microdisk (micromember) 10 referred to as lasing disk in Figure 1 and a second upper, transparent waveguiding microdisk (micromember) 12 referred to as guiding disk in Figure 1 disposed in a different plane (different epitaxial level during epitaxial layer growth) from the lower microdisk 10 so as to have low light absorption. The first lower lasing microdisk 10 and second upper waveguiding microdisk 12 are shown having the sam diamet rs. Th first lower lasing microdisk 10 can b excited by suitabl means such as optically (.g. by a pumping laser providing pulsed light of appropriat duty cycle) or electrically (.g. by electrical current pulses of appropriate duty cycle via lead wires attached to a top and bottom of the micromember) as is known.

[0016] The lower lasing microdisk 10 and th upper waveguiding microdisk 12 are optically coupled by resonant photon tunnelling by being spaced apart a selected distance from one another with a material having a lower refractive index disposed between the micromembers. In Figure 1, the microdisks 10,12 are spaced apart by a pedestal 14 comprising InP, although the invention is not so limited as the microdisks also could be suspended or otherwise spaced to provide a low refractive index material, such as air, SiO_2, acrylic or semiconductor (e.g. InP), therebetween to provide resonant photon tunnelling therebetween. The lower lasing microdisk 10 is connected to a lower substrate by an integral upstanding pedestal 16. The upper waveguiding disc 12 includes a circumferential V-shape or wedge-shaped opening or notch 18 as a light output coupling from the laser.

[0017] The double microdisk laser shown in Figure 1 was formed by molecular beam epitaxial growth of layers of the InGaAs/InGaAsP and then shaping the layers to the double disk configuration shown by multistep photolithographic techniques and selective reactive ion etching techniques. In particular, an initial $In_{0.84}Ga_{0.16}As_{0.33}P_{0.67}$ etch stop layer was grown on the top of the semiinsulating (100) InP substrate shown in Figure 1. Then, a 1.0 micron thick InP pedestal layer was grown on the etch stop layer. A 0.2 micron thick microcavity quantum well (MQW) layer was grown on the pedestal layer. The MQW layer was grown to comprise three (3) $In_{0.53}Ga_{0.47}As$ quantum layers or wells each of approximate 100 Angstroms thickness sandwiched by $In_{0.84}Ga_{0.16}As_{0.33}P_{0.67}$ barrier layers of approximate 100 Angstroms thickness with end caps having the barrier composition of approximate 700 Angstroms thickness. A second InP pedestal layer having a 0.65 micron thickness was grown on the MQW layer followed by a final passive layer of $In_{0.84}Ga_{0.16}As_{0.33}P_{0.67}$ to a thickness of approximately 0.2 micron as the top guiding microdisk layer. Other suitable material systems (e.g. InGaAs/InAlGaAs) can be used to fabricate the laser.

[0018] Multi-step photolithographic techniques were used to fabricate the the double-disk lasers having outer diameters of 3 microns in one trial and 10 microns in another trial. The opening 18 was patterned first using an AZ-1350J photoresist and etched down around 0.4 micron using reactive ion etching without etching the MQW layer. After removing the photoresist, the circular cross-section microdisks 10, 12 were patterned and carefully aligned with the opening. Then, reactive ion etching was used again to etch the circular patterns down vertically (approximately 1.2 microns) into the bottom pedestal layer to form the microdisks 10, 12 having a right cylindrical shap (i.e. a circumferential sidewall

substantially p rpendicular to th axial microdisk ends) and smooth circumf r ntial sidewall. In both reactiv ion etching steps, a gas mixtur comprising a methane, hydrogen, and argon in a ratio of 5:17:8 was used under a gas pressure of 45 millitorr and a plasma beam power of 90 Watts. A highly selective HCl etchant (such as 10 volume % HCl aqueous solution) was then used to clear the remaining pedestal layers horizontally to form the two supporting InP pedestals or pillars 14,16 shown in Figure 1. The etched InP pedestals or pillars exhibited a rhombus shape upon examination under scanning electron microscope as a result of anisotropic etching of the InP material.

[0019] The upper microdisk 12 of the double-disk laser comprises a basically passive, absorptionless material at a different epitaxial level (during layer growth) for light guiding purposes. The photons generated in the lower MQW microdisk 10 leak slowly out into the upper waveguiding microdisk 12 via resonant waveguide coupling (resonant photon tunneling) through the InP pedestal or pillar 14. The coupling efficiency between the MQW microdisk 10 and the waveguiding microdisk 12 can be controlled by appropriately selecting the distance of separation between the microdisks 10, 12; e.g. about 0.65 micron in the fabrication of the 3 micron and 10 micron diameter microdisks described hereabove. As the separation distance between the microdisks 10, 12 increases, the coupling efficiency decreases. Figure 2 shows an estimate of the coupling percentage per roundtrip length versus the coupling length (which is approximately the circumference of the microdisk structure) for a 0.65 micron separation between the microdisks 10,12. The coupling length is the roundtrip length of the photons propagating around the circumference of the microdisk, given approximately by πD, where D is the microdisk diameter. As can be seen, about 0.1% to 1% coupling efficiency was estimated for a microdisk diameter ranging from 5 to 20 microns. This double-microdisk structure enables the MQW microdisk resonator to maintain a near perfect microdisk shape with associated high Q value and low lasing threshold, while a light output coupling feature or structure can be provided on the upper waveguiding microdisk 12 to couple light out of the laser. By providing the light output coupling 18 on the upper waveguiding microdisk 12, the high Q value and low lasing threshold of the lower MQW microdisk is not adversely affected.

[0020] In Figure 1, the light output coupling comprises V-shaped opening 18 interrupting the circumference of the upper waveguiding microdisk 12 so as to direct the light out from the double-microdisk laser. The opening 18 forms flat surfaces or windows 18a, 18b through which light can be coupled out from the laser.

[0021] The lasing characteristics of the double-microdisk laser (microdisk diameter of 10 microns) of th pr sent invention were analyzed by optical xcitation using a Nd:YAG pump las r at 1064 nanometer. The pump laser was modulated by an acousto-optic modulator with a varying duty cycle and focus d to a spot size covering th ntir axial nd qual to or larger than the area of microdisk 10. The double-microdisk laser was cooled down to liquid nitrogen temperature. The mission from the doubl -microdisk laser was collected by an objective lens dispersed by an optical grating spectrometer (resolution of 1 nanometer) and detected using a lock-in technique and a liquid-nitrogen cooled germanium detector.

[0022] Figure 3 shows the lasing spectra obtained from the double-microdisk laser (10 microns diameter) at and above the lasing threshold. The solid data line relates to pump power above threshold, whereas the dashed data line relates to pump power at the threshold. The threshold is where the peak pump laser power is approximately 500 microWatts with a 1 microsecond pulse width and 1% duty cycle to reduce the heating. For comparison purposes, a double-microdisk laser without the opening 18 (i.e. having an uninterrupted circumference on the upper microdisk 12) was fabricated and tested for emission under the same conditions. The comparison double-microdisk laser without the light output coupling opening 18 exhibited a lower lasing threshold (approximately 300 microWatts) as a result of the lower light loss from the upper waveguiding microdisk. This is also the typcial threshold value for a single microdisk laser with the same material composition and diameter as the bottom micordisk 10.

[0023] The lasing threshold of double-microdisk laser with a 3 micron disk diameter of the invention having the opening 18 in the upper micordisk 12 was determined to be approximately 25 microWatts, which is almost the same as that of a single microdisk laser with same diameter with an uninterrupted circumference. This result is indicative that the double-microdisk laser of the invention with opening 18 provides a high Q microcavity without deteriorating the lasing threshold.

[0024] The directional lasing output from the opening 18 of the upper waveguiding microdisk 12 of the double-microdisk laser of the invention was imaged using an infrared camera having an imaging tube with a substrate spaced about 10 microns from the flat surfaces 18a, 18b. The image of the lasing output of the opening 18 is shown in Figure 4 where it is can be seen that lasing light is scattered from the microdisk 12 itself as well as from a strong edge-emitting spot from light escaping the opening 18 and striking the imaging substrate at about 10 microns from the opening 18. The image was taken at a pumping power twice that of the threshold value. In order to obtain the image, the pump laser had to be strongly attenuated with filters before the infrared camera. As a result of the focusing difference between the substrate 29 and the microdisk 12 itself, the image was refocused to see the light output opening on the microdisk and the top view of th doubl -microdisk was retraced using th dashed line shown in Figure 4. Figure 4 clearly shows that th op ning 18 on the upper waveguiding microdisk 12 provides a leakag source of

the lasing photons and directs th lasing light out from the double-microdisk laser. Th bright dot on the imag is due to a burned spot on the infrared imaging tub .

[0025] In lieu of the opening 18 shown in Figur 1 as a light output coupling from the double-microdisk laser, a grating, surface or opening having a 45 degree or other suitable angle can be formed on the upper axial end of the waveguiding microdisk 12 to provide a vertical component of lasing light emission from the upper microdisk 12 of the laser.

[0026] Referring to Figures 5-7, an alternative example of a microcavity semiconductor laser is illustrated schematically as including a first upper microcylinder (micromember) 20 referred to as lasing cylinder in Figures 5-6 and a second lower transparent waveguiding microdisk (micromember) 22 referred to as guiding cylinder in Figures 5-6 disposed in a different (lower) plane or epitaxial level (during epitaxial layer growth) from the microcylinder 20 and having low light absorption. The upper lasing microcylinder 20 is spaced a distance from the lower waveguiding microcylinder 22 to provide optical coupling therebetween by resonant photon tunnelling. The microcylinders 20,22 are spaced apart by a microcylinder 24 comprising InP to this end. The lower guiding microcylinder 22 is supported on the lower InP substrate 29 shown. The lower waveguiding microcylinder 22 includes a linear light output waveguide 28 integral therewith as a light output coupling from the laser.

[0027] The double microcylinder laser shown in Figures 5-7 can be formed by molecular beam epitaxial growth of layers of the InGaAs/InGaAsP system (or other suitable material systems) described above for the double microdisk embodiment and then shaping the layers to the double microcylinder configuration shown by the multistep photolithographic techniques and selective reactive ion etching techniques in similar manner as described above for the double microdisk laser. For example, the MQW layer can be grown with x and y values selected to provide three $In_{0.53}Ga_{0.47}As$ quantum layers or wells each of approximate 100 Angstroms thickness sandwiched by $In_{0.84}Ga_{0.16}As_{0.33}P_{0.67}$ barrier layers of approximate 100 Angstroms thickness with end caps having the barrier composition/thickness as described above. A lower buffer layer is provided on the substrate and comprises InP of approximately 1000 Angstrom thickness, while a top cap comprising InP of 1 micron thickness can be provided on the MQW layer.

[0028] The lower microcylinder 22 of the double-microcylinder laser comprises a basically passive material with low absorption for light guiding purposes. The photons generated in the upper MQW lasing microcylinder 20 leak slowly out into the lower waveguiding microcylinder 22 via the resonant waveguide coupling microcylinder 28. As mentioned hereabove, the coupling efficiency between the lasing microcylinder 20 and the waveguiding microcylinder 22 can be controlled by selecting the distanc of separation therebetween. As the separation distance between th microcylinders 20, 22 increases, the coupling efficiency decr ases. The linear light output waveguid 28 int gral with the low r microcylinder 22 includes material layers in a sequence like that of the lower micromember 22 sinc it is formed integrally therewith and provides a light output coupling from the laser that is at a level on the substrate 29 compatible with integrated optical circuits present on the substrate 29 so as to provide light output signals to the optical circuit.

[0029] Double microcylinder lasers of the invention are advantageous in that they have much shorter cavity lengths than the usual conventional semiconductor lasers. This enables the double microcylinder lasers of the invention to have a large frequency tunability without mode hopping via direct injection current control. The cavity length for usual conventional semiconductor lasers is 0.3 mm with an actual optical path of about 1 mm. With such a long optical path, the usual conventional laser has approximately 50 cavity resonance modes under the gain curve of the active medium. Because of the large number of frequency modes, the frequency spacing between two adjacent modes is small. As a result of the small frequency spacing, the laser frequency tunability is limited. In contrast, the double microcylinder lasers of the invention have short cavity lengths and contain much fewer cavity resonance modes (e.g. 1-5 modes) under the gain curve. The fewer number of resonance modes allows a larger frequency tunability via direct current control without frequency hopping.

[0030] Due to the low-loss high Q cavities, the microcavity lasers of the invention have high intra-cavity intensities. The high intra-cavity intensities will give rise to high stimulated emission rates, leading to fast carrier response time for the carrier density under direct current modulations. The fast carrier response time combined with the small size of the microcavities should lead to increased modulation bandwidths.

[0031] Referring to Figure 8, an embodiment according to the invention is illustrated comprising a lower micromember (microdisk or microcylinder) 50 and an upper micromember (not shown) identical to the lower micromember 50 and having features like those described hereabove. The lower micromember 50 can be a waveguiding micromember while the upper micromember (not shown) can be a lasing micromember. Alternately, the lower micromember 50 can be a lasing micromember while the upper micromember (not shown) can be a waveguiding micromember. The micromember 50 may have different diameters and different shapes at some expense of lowering the optical coupling efficiency between the micromembers. The lower and upper micromembers are spaced a distance apart in a manner described above to provide optical coupling therebetween by resonant photon tunnelling. The lower micromember 50 can be disposed on SiO_2 layers on a GaAs substrate as shown and described below. An arcuate light output waveguide 52 is disposed about the lower micromember 50. The waveguide 52 can be int -

gral with or spaced from the micromember 50 to provide a gap or distanc that provides optical output coupling by resonant photon tunnelling. Th waveguide 52 can have typical dimensions of 0.2 to 2 micron width and 0.1 to 1 micron height. A gap up to 1.0 micron wid (.g. 0.5 micron wide) typically has been used to this end. The light output waveguide 52 includes an arcuate, circular portion 52a that is spaced from and encircles the circumferential periphery (e.g. about 180 degrees of the circumference) of the lower micromember 50 and extends in one or more linear, parallel legs 52b (two shown) that terminate in flat ends 52c that provide light output at a level on the GaAs substrate compatible with integrated optical circuits present on the substrate so as to provide light output signals to the optical circuit.

[0032] When the lower micromember 50 is a lasing micromember, the waveguide 52 can comprise the same material layer sequence as the lasing micromember and would be optically pumped. Alternately, the waveguide 52 can comprise the above-described transparent InGaAsP waveguide material free of quantum wells without optical pumping. When the lower micromember 50 is a waveguiding micromember, the waveguide 52 will comprise the same transparent material without quantum wells as the waveguiding micromember without optical pumping.

[0033] Figure 9 illustrates schematically another embodiment of the invention similar to that of Figure 8 with the exception that a lower microannulus 50' is employed in lieu of the lower microdisk or microcylinder of Figure 8. The lower microannulus 50' can be a waveguiding micromember while the identical upper microannulus (not shown) can be a lasing micromember. Alternately, the lower microannulus 50' can be a lasing micromember while the upper microannulus (not shown) can be a waveguiding micromember. The microannulus can have an outer diameter similar to that described hereabove for the microdisks and microcylinders with a typical ring or annulus width of 0.2 to 2 microns and height of 0.2 to 1 micron. In Figure 9, like features of Figure 8 are designated by like reference numerals primed.

[0034] The lasers shown in Figures 8 and 9 having the dimensions described can be formed by molecular beam epitaxial growth of layers of the InGaAs/InGaAsP system (or other suitable material systems) as described hereabove and then shaping the layers to the double microcylinder configuration shown by the multistep photolithographic techniques and selective reactive ion etching techniques in similar manner as described hereabove for the double microdisk laser. When dimensions of the microcylinder or microannulus 50' are further reduced to, for example, a 0.4 micron ring or annulus width and 0.2 micron height, a different fabrication process can be used involving nanofabrication techniques including electron-beam (e-beam) lithography and reactive ion etching (RIE). For exampl , an InP substrate can b coated with an epitaxial InGaAsP/InGaAs laser lay r structure of 0.19 micron thickness. Within th layer structure, three 100 Angstrom thick quantum w ll layers ($In_{0.53}Ga_{0.47}As$) can be separated by 100 Angstrom thick barrier layers ($In_{0.84}Ga_{0.16}As_{0.33}P_{0.67}$). They can be sandwiched by two 700 Angstrom thick ($In_{0.84}Ga_{0.16}As_{0.33}P_{0.67}$) layers on both sides.

[0035] A wafer bonding and etching technique can be used to transfer the thin microannulus 50' on top of a low-index SiO_2 cladding on a GaAs substrate. First, 800 Angstrom thick SiO_2 is deposited on the wafer via plasma enhanced chemical vapor deposition (PECVD). Electron-beam lithography is used to write the microannulus pattern on PMMA (poly methyl methylmethacrylate) coated on top of the SiO_2 layer. The pattern then is transferred down to the SiO_2 layer by etching away the unmasked region using the RIE process with CHF_3 as the etchant gas under 31 millitorrs with 60 Watts plasma power and then the PMMA is removed. The pattern on SiO_2 then forms the mask for subsequent etching of the InGaAsP layer. The RIE process is used to etch the microannulus down vertically through the 0.19 micron InGaAsP/InGaAs epitaxial layer structure into the InP substrate. In this step, a gas mixture of methane, hydrogen, and argon can be used in a ratio of 10:34:10 under a gas pressure of 45 millitorrs and a plasma beam power of 90 Watts plasma power.

[0036] In order to place the thin microannulus structure on a low-refractive-index material, the substrate is removed as follows. The RIE etched sample is deposited with 0.75 micron thick SiO_2 using PECVD. A piece of GaAs substrate covered with 0.75 micron thick SiO_2 deposited via PECVD is then prepared. The two substrates are SiO_2 face-to-face bonded together using acrylic. Finally, a highly selective HCl etchant (HCl plus H_3PO_4 in 1:1 ratio) was used to remove the InP substrate, leaving the microannulus laser structure on 1.5 micron thick SiO_2 on the GaAs substrate.

[0037] In the practice of the present invention, the estimated number of cavity modes with frequencies in the photoluminescence spectrum are less than two (single mode) if the diameter of the micromember is less than 5 microns and the spectral gain width of the quantum well is of the typical value of 60 nanometers. Microcavity outer diameters in the range of 2 microns to 5 microns are preferred to this end. However, the invention is not so limited and can be practiced using a lasing microcavity comprising one or more active quantum well (MQW) layers having a general circular cross-sectional periphery with a diameter up to 30 microns for example, such as from 10 to 30 microns, to provide an active optical medium that supports waveguiding optical modes, which include, but are not limited to, the whispering gallery mode. The invention also is not limited to the particular micromembers described and shown in the drawings and can be practised using microdisk, microcylinder, microannulus (microring) and other shape micromembers so dimensioned as to provide an activ optical medium that supports waveguiding optical modes.

Claims

1. Laser comprising a first micromember having a lasing microcavity with a substantially circular cross-sectional periphery and a second waveguiding micromember (50; 50') spaced from the first micromember in a different plane and optically coupled to the first micromember, the second waveguiding micromember (50; 50') including a light output coupling (52; 52') comprising an arcuate output waveguide encircling a portion of the second waveguiding micromember (50; 50') for providing light output from the laser.

2. The laser of Claim 1, wherein the first micromember comprises a microdisk.

3. The laser of Claim 1 or 2, wherein the second waveguiding micromember (50; 50') comprises a microdisk.

4. The laser of Claim 1 wherein the first micromember comprises a microcylinder.

5. The laser of Claim 1 or 4, wherein the second waveguiding micromember (50; 50') comprises a microcylinder.

6. The laser of Claim 1, wherein the first micromember comprises a microannulus.

7. The laser of Claim 1 or 6, wherein the second waveguiding micromember (50; 50') comprises a microannulus.

8. The laser of any one of the preceding claims, wherein the micromembers (50; 50') are spaced a distance apart with a material of lower refractive index therebetween to provide optical coupling between micromembers (50; 50').

9. The laser of any one of the preceding claims, wherein the arcuate output waveguide (52; 52') comprises a circular portion (52a; 52a') encircling the portion of the second micromember (50; 50') and at least one linear portion (52b; 52b') terminating in an end (52c; 52c').

10. The laser of any one of the preceding claims, wherein the first micromember and second waveguiding micromember are spaced apart by a distance selected to provide a given coupling efficiency therebetween.

11. Th laser of any one of the preceding claims, wh rein the first micromember comprises InGaAs semiconductor.

12. The las r of Claim 11, wh rein the second waveguiding micromember comprises InGaAsP semiconductor.

13. The laser of Claim 11 or 12, wherein the optical coupling comprises InP.

14. The laser according to any one of the preceding claims, further comprising a substrate in which the first micromember is spaced above the substrate, and the second micromember is spaced above the first micromember.

15. The laser according to any one of Claims 1 to 13, further comprising a substrate, in which the first micromember is spaced above the substrate, and the second micromember is between the first micromember and the substrate.

16. The laser of Claim 15, wherein the light output coupling comprises a waveguide at a level on the substrate compatible with an integrated optical circuit present on the substrate so as to provide light output signals to the optical circuit.

Patentansprüche

1. Laser, der ein erstes Mikroglied mit einem Lasermikrohohlraum mit einer Peripherie mit einem im wesentlichen runden Querschnitt aufweist und ein zweites wellenleitendes Mikroglied (50; 50'), das von von dem ersten Mikroglied in einer anderen optischen Ebene beabstandet ist, und das an das erste Mikroglied optisch gekuppelt ist, wobei das zweite wellenleitende Mikroglied (50; 50') eine Lichtausgabekupplung (52; 52') einschließt, die einen gekrümmten Ausgabewellenleiter aufweist, der ein Teil des zweiten wellenleitenden Mikroglieds (50; 50') umkreist, um Lichtausgabe von dem Laser zu liefern.

2. Laser nach Anspruch 1, in dem das erste Mikroglied eine Mikroscheibe aufweist.

3. Laser nach Anspruch 1 oder 2, in dem das zweite wellenleitende Mikroglied (50; 50') eine Mikroscheibe aufweist.

4. Laser nach Anspruch 1, in dem das erste Mikroglied einen Mikrozylinder aufweist.

5. Laser nach Anspruch 1 oder 4, in dem das zweite wellenleitende Mikroglied (50; 50') einen Mikrozylinder aufw ist.

6. Las r nach Anspruch 1, in dem das erste Mikroglied einen Mikroring aufweist.

7. Laser nach Anspruch 1 oder 6, in dem das zw ite w llenleitend Mikroglied (50; 50') ein n Mikroring aufweist.

8. Laser nach einem der vorhergehenden Ansprüche, in dem die Mikroglieder (50; 50') mit einem Abstand voneinander beabstandet sind, mit einem Material mit geringerem Brechungsindex dazwischen, um optische Kupplung zwischen Mikrogliedern (50; 50' zu liefern.

9. Laser nach einem der vorhergehenden Ansprüche, in dem der gekrümmte Ausgabenwellenleiter (52; 52') ein rundes Teil (52a; 52a') aufweist, das das Teil des zweiten Mikroglieds (50; 50') umkreist, und wenigstens ein lineares Teil (52b; 52b'), das in einem Ende (52c; 52c') endet.

10. Laser nach einem der vorhergehenden Ansprüche, in dem das erste Mikroglied und das zweite wellenleitende Glied mit einem Abstand voneinander beabstandet sind, der ausgewählt ist, um eine gegebenen Kupplungswirkungsgrad dazwischen zu liefern.

11. Laser nach einem der vorhergehenden Ansprüche, in dem das erste Mikroglied einen InGaAs-Halbleiter aufweist.

12. Laser nach Anspruch 11, in dem das zweite wellenleitende Mikroglied einen InGaAsP-Halbleiter aufweist.

13. Laser nach Anspruch 11 oder 12, in dem die optische Kupplung InP aufweist.

14. Laser nach einem der vorhergehenden Ansprüche, der weiterhin ein Substrat aufweist, in dem das erste Mikroglied über dem Substrat beabstandet ist, und das zweite Mikroglied über dem ersten Mikroglied beabstandet ist.

15. Laser nach einem der Ansprüche 1 bis 13, der weiterhin ein Substrat aufweist, in dem das erste Mikroglied über dem Substrat beabstandet ist, und das zweite Mikroglied zwischen dem ersten Mikroglied und dem Substrat ist.

16. Laser nach Anspruch 15, in dem die Lichtausgabekupplung einen Wellenleiter auf einer Höhe auf dem Substrat aufweist, der mit einem integrierten optischen Kreis verträglich ist, der auf dem Substrat vorhanden ist, um dem optischen Kreis Lichtausgabesignale zu liefern.

R v ndicati ns

1. Laser comprenant un premier micromembre ayant une microcavité à effet laser avec une périphérie à section en coupe sensiblement circulaire t un deuxième micromembre guide d'ondes (50; 50') espacé du premier micromembre dans un plan différent et optiquement couplé au premier micromembre, le deuxième micromembre guide d'ondes (50; 50') comprenant un couplage de lumière émise (52; 52') comprenant un guide d'ondes d'émission en forme d'arc encerclant une partie du deuxième micromembre guide d'ondes (50; 50') pour fournir la lumière émise par le laser.

2. Laser selon la revendication 1, dans lequel le premier micromembre comprend un microdisque.

3. Laser selon la revendication 1 ou 2, dans lequel le deuxième micromembre guide d'ondes (50; 50') comprend un microdisque.

4. Laser selon la revendication 1 dans lequel le premier micromembre comprend un microcylindre.

5. Laser selon la revendication 1 ou 4, dans lequel le deuxième micromembre guide d'ondes (50; 50') comprend un microcylindre.

6. Laser selon la revendication 1, dans lequel le premier micromembre comprend un microanneau.

7. Laser selon la revendication 1 ou 6, dans lequel le deuxième micromembre guide d'ondes (50; 50') comprend un microanneau.

8. Laser selon l'une quelconque des revendications précédentes, dans lequel les micromembres (50; 50') sont espacés d'une certaine distance avec un matériau d'indice de réfraction inférieur dans l'intervalle pour fournir un couplage optique entre les micromembres (50; 50').

9. Laser selon l'une quelconque des revendications précédentes, dans lequel le guide d'ondes d'émission en forme d'arc (52; 52') comprend une partie circulaire (52a; 52a') encerclant la partie du deuxième micromembre (50; 50') et au moins une partie linéaire (52b; 52b') se terminant en une extrémité (52c; 52c').

10. Laser selon l'une quelconque des revendications précédentes, dans lequel le premier micromembre et le deuxième micromembre guide d'ondes sont espacés d'un distance choisie pour fournir dans l'intervalle une fficacit´ d couplage donné .

11. Laser selon l'une quelconque des revendications

précédentes, dans lequel le pr mier microm mbr comprend un semi-conducteur InGaAs.

12. Laser selon la rev ndication 11, dans lequel le deuxième micromembr guid d'ondes compr nd un semi-conducteur InGaAsP.

13. Laser selon la revendication 11 ou 12, dans lequel le couplage optique comprend InP.

14. Laser selon l'une quelconque des revendications précédentes, comprenant en outre un substrat dans lequel le premier micromembre est espacé au dessus du substrat, et le deuxième micromembre est espacé au dessus du premier micromembre.

15. Laser selon l'une quelconque des revendications 1 à 13, comprenant en outre un substrat dans lequel le premier micromembre est espacé au dessus du substrat, et le deuxième micromembre se situe entre le premier micromembre et le substrat.

16. Laser selon la revendication 15, dans lequel le couplage de lumière émise comprend un guide d'ondes à un niveau sur le substrat compatible avec un circuit optique intégré présent sur le substrat de façon à fournir des signaux de lumière émise au circuit optique.

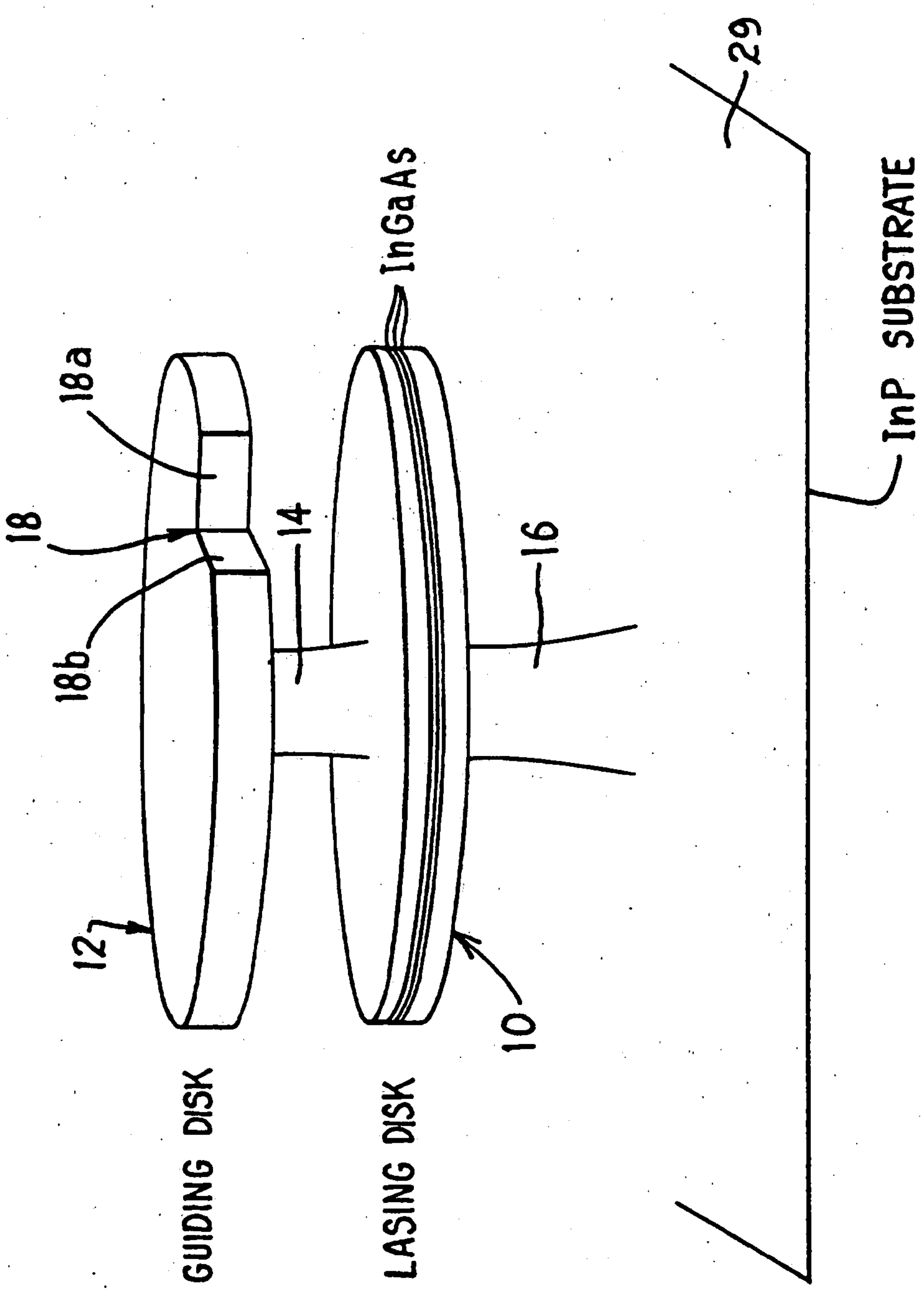
18a
18
18b
14
16
12
10
InGaAs
GUIDING DISK
LASING DISK
29
InP SUBSTRATE

FIG. 1

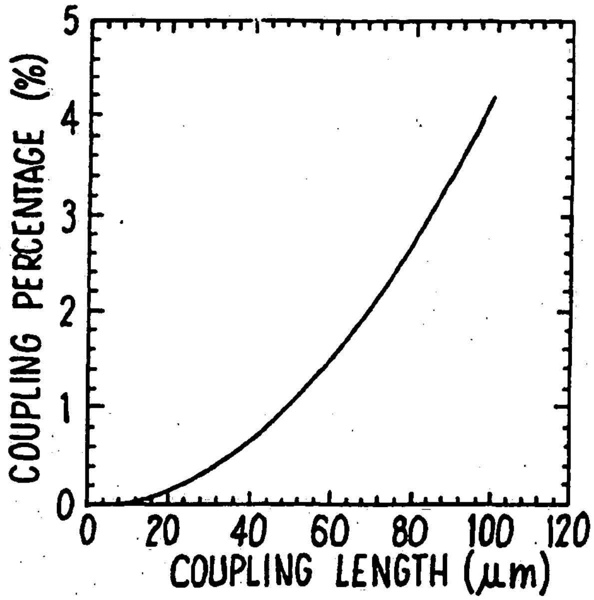
COUPLING PERCENTAGE (%)
0
1
2
3
4
5
0
20
40
60
80
100
120
COUPLING LENGTH (μm)

FIG. 2

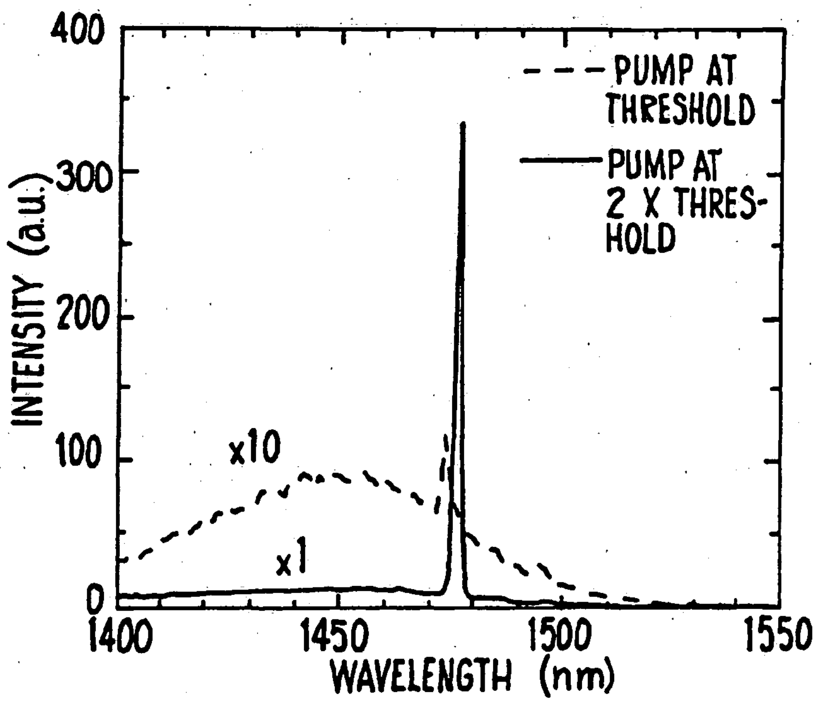
INTENSITY (a.u.)
0
100
200
300
400
1400
1450
1500
1550
WAVELENGTH (nm)
PUMP AT THRESHOLD
PUMP AT 2 X THRESHOLD
x10
x1

FIG. 3

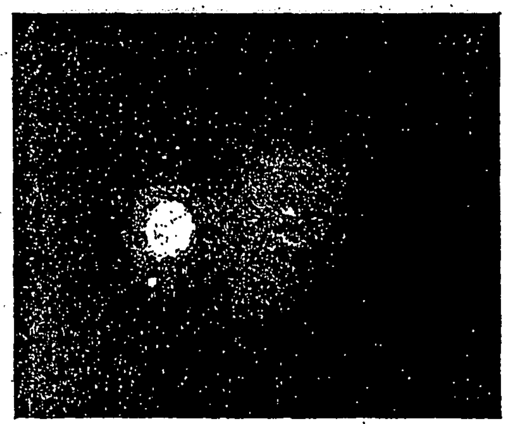

FIG. 4

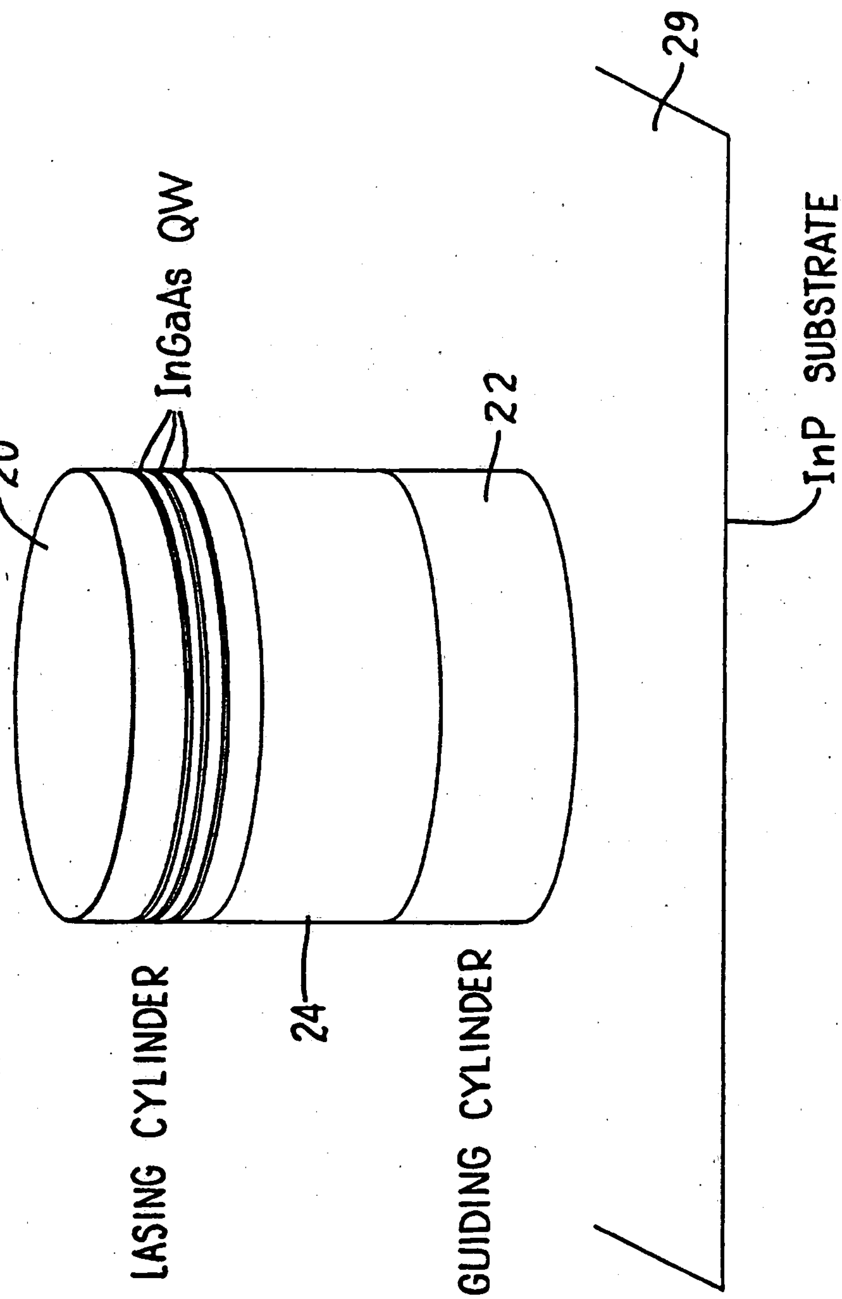
20
InGaAs QW
22
29
InP SUBSTRATE
LASING CYLINDER
24
GUIDING CYLINDER

FIG. 5

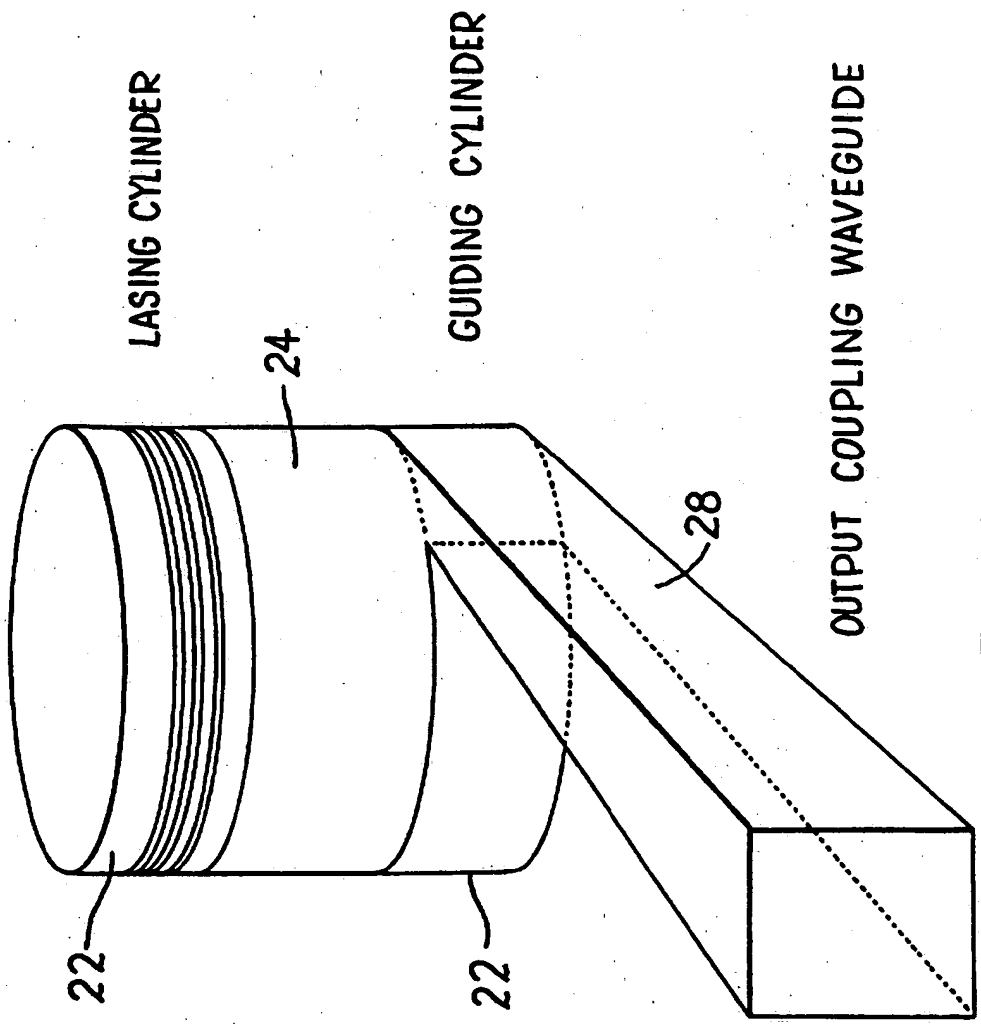
LASING CYLINDER
GUIDING CYLINDER
OUTPUT COUPLING WAVEGUIDE
24
28
22
22

FIG. 6

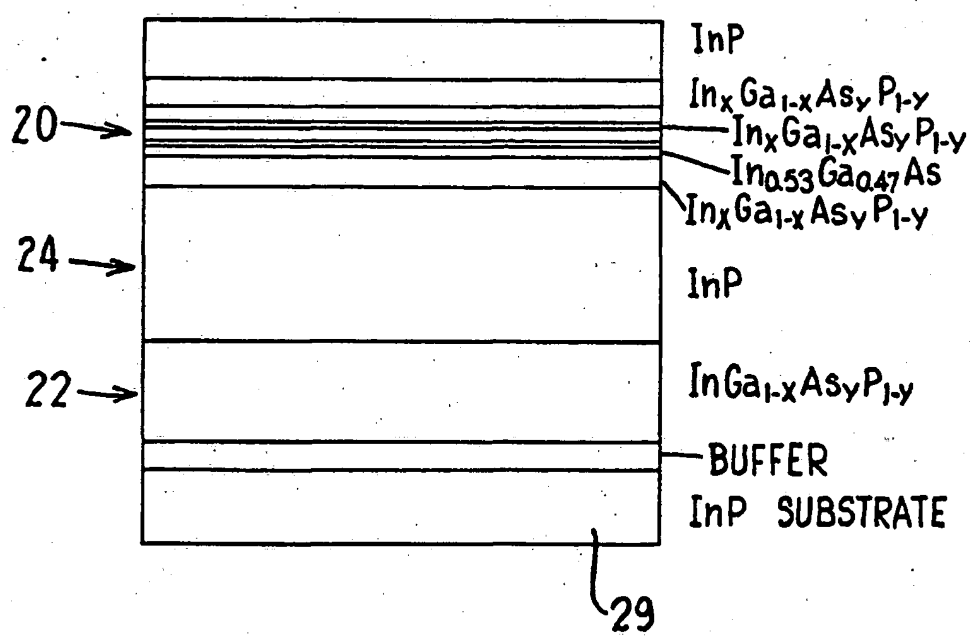
InP
$In_xGa_{1-x}As_yP_{1-y}$
20
$In_xGa_{1-x}As_yP_{1-y}$
$In_{0.53}Ga_{0.47}As$
$In_xGa_{1-x}As_yP_{1-y}$
24
InP
22
$InGa_{1-x}As_yP_{1-y}$
BUFFER
InP SUBSTRATE
29

FIG. 7

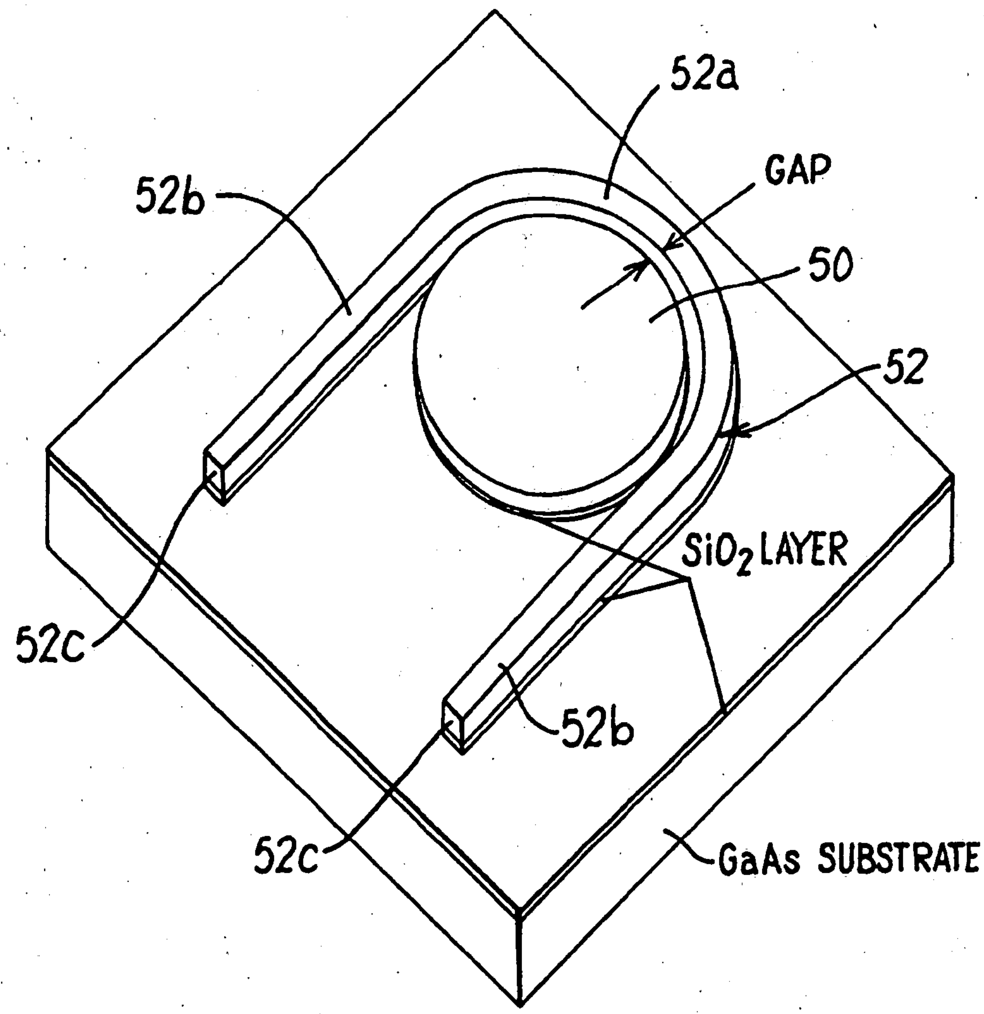

FIG. 8

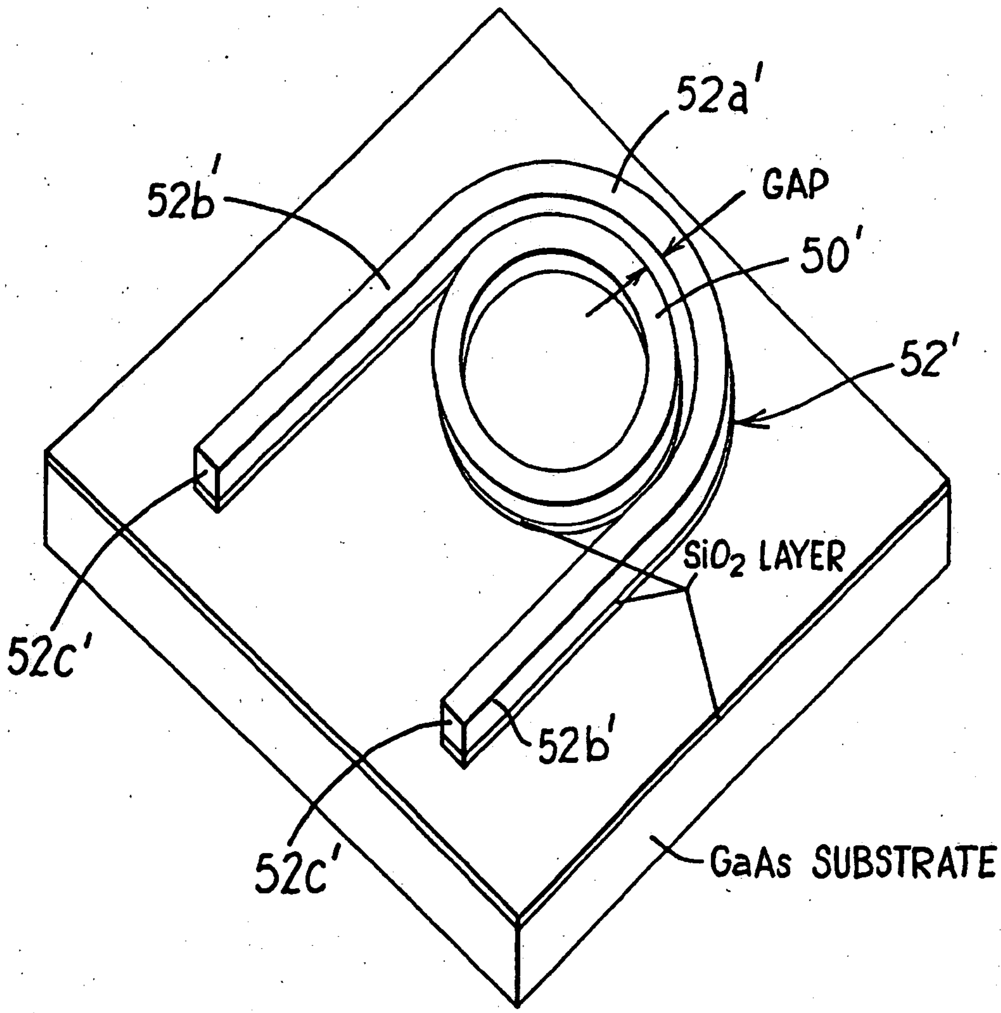

FIG. 9